Zone Clusters: A Virtual Cluster Based Upon Solaris Containers

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***Abstract*—Virtualization is a powerful technology used primarily for consolidating applications that must be isolated on the same hardware. There are multiple forms of virtualization including both Operating System Virtualization and Virtual Machines. This paper introduces the Zone Cluster, which is a virtual cluster that uses operating system virtualization. Each Zone Cluster node is an operating system virtualization environment on a separate machine, which can be a virtual machine or a physical machine. The paper explains the benefits of Zone Clusters and describes how Zone Clusters were implemented. The paper explores the performance implications of virtualization by reporting file system, network, and application benchmark results for a cluster with no virtualization, zone cluster on physical machines, a cluster on virtual machines, and a zone cluster on virtual machines.**

I. Introduction

The increasing power of computing hardware, as exemplified by Moore's Law, is impacting the way computers are used. At one time it was common for many people to put one large application or a relatively small set of applications on one system. With current systems that approach is terribly inefficient in many cases. Virtualization provides a way to carve one physical system into multiple virtual systems that can each host applications independently.

There are multiple technologies for creating virtual systems, and two technologies are of particular interest: virtual machines, and operating system virtualization. All of these technologies were introduced initially for single machine systems. Since our area of interest is high availability clusters, we are going to look at applying these technologies to high availability clusters. The cluster software that we use is Solaris Cluster, also called Sun Cluster [2], and this software runs on the Solaris Operating System.

The virtual machine technology presents the illusion to the cluster software that a virtual machine is a physical machine. When the illusion is good enough, the cluster software can run on the virtual machine as if the virtual machine were a physical machine. On SPARC machines we use a virtual machine technology called a Logical Domain or LDom. One virtual machine controls the overall system, and is called the Control Domain. An LDom that has direct access to physical devices is called an IO Domain. Note that the Control Domain is usually also an IO Domain. An LDom without direct access to physical devices is called a Guest LDom. Applications typically run in Guest LDoms, while the other LDoms support the Guest Domains. Solaris Cluster now runs on virtual machines, each called an LDom Guest Domain, as if they were physical machines.

Operating system virtualization provides different tradeoffs from virtual machines. We chose to implement the Zone Cluster [3], which is a virtual cluster based upon operating system virtualization. The Zone Cluster is the primary focus of this paper.

This paper first identifies the primary uses for Zone Clusters in section II. This paper then provides an overview of how Zone Clusters were implemented in section III. Next we use multiple benchmarks to compare the performance of a Global Cluster on physical machines, a Zone Cluster on physical machines, a Global Cluster on virtual machines, and a Zone Cluster on virtual machines in section IV. The paper concludes with a summary of major findings and future directions in section V.

II. Zone Cluster Use Cases

This section identifies a number of primary use cases that are covered in their own subsections. This section also discusses some motivations for running Zone Clusters with virtual machines.

1) Multiple Organization Consolidation: The applications from almost any number of organizations can be consolidated one one system in different Zone Clusters. Figure 1 shows an example cluster configuration with three Zone Clusters belonging to different organizations on a 4-node cluster. This cluster also has a Global Cluster that is not shown.

The consolidation of applications on to a single system belonging to multiple organizations leads to following primary requirements:

- Security Isolation - The solution must ensure that applications and users from different organizations cannot see and cannot affect others.

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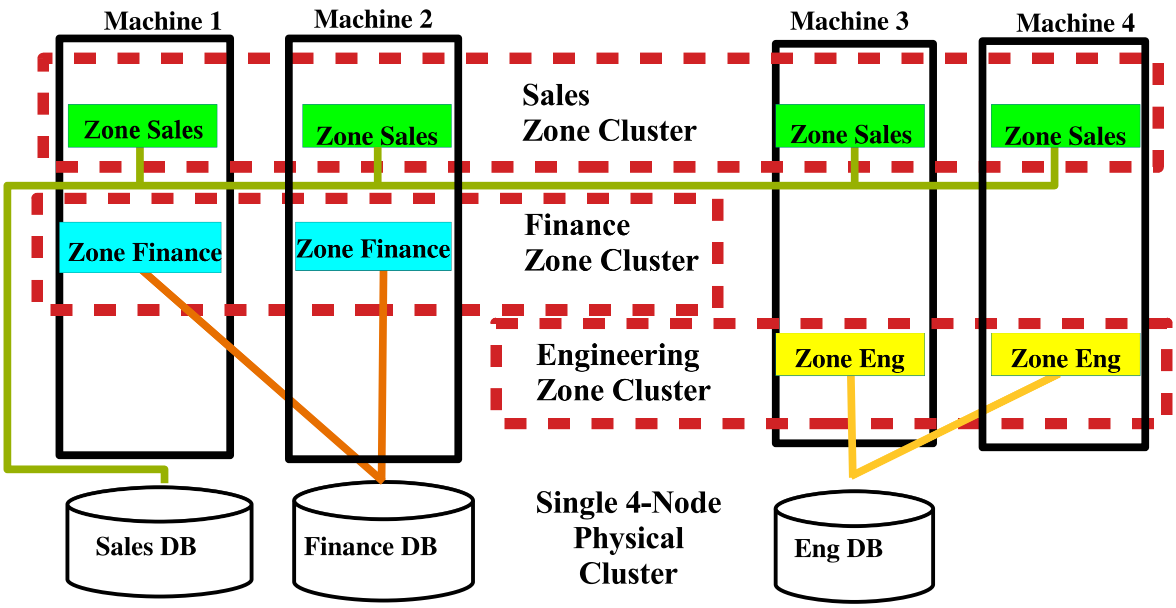

Fig. 1. Three Zone Clusters on 4-Machine Physical Cluster

- Application Fault Isolation - Some cluster applications originated in the days when they had a cluster all to themselves. Such application will reboot machines in order to recover from some error conditions. Different organizations do not want their schedules impacted by problems in other areas. So one application problem must not affect applications in other areas.
- Resource Management - Computer resources are not free. So organizations demand that they receive resources for which they have paid. The solution must provide the administrator with controls on system resources that can not be undermined by the various organizations.

2) Functional Consolidation: Many of our customers have three separate clusters. The actual production environment has its own cluster. The development organization has a cluster to fix problems or develop new solutions. The test organization has a cluster to validate that software changes work as desired. In the high availability cluster world, many people do not allow anything except production processing to happen on the production cluster. Virtual clusters make it possible for the development and test organizations to share a physical cluster. Boot and halt operations on one virtual cluster do not affect another virtual cluster. Virtual clusters can be created and destroyed at any time. Functional consolidation raises the possibility that the engineers can all work during normal hours, instead of signing up for machines at inconvenient hours.

3) Multiple Tier Consolidation: The Data Center Front-End Tier, Application Tier, and Database Tier applications have run on separate clusters in many installations. The virtual cluster facilitates consolidating these applications on to a single physical system. The computing resources needed by the different tiers typically varies considerably. Resource management controls ensure that the various tiers receive the needed resources.

4) Cost Containment: Software vendors commonly charge license fees for cluster applications that are based on the number of CPUs that are available for that application. The administrator can place an application in a Zone Cluster and then use resource management controls to limit the number of CPUs available to each Zone Cluster node. The number of CPUs in the Zone Cluster node can be used as the number of CPUs for license fee purposes, at least with some vendors.

When the administrator consolidates multiple applications on a single system, presumably each of those applications will be consuming CPU resources. In many cases, the applications will be covered by different licenses. The administrator can then reduce the license fees to just the actual number of CPUs needed for each of the different applications. The cost savings can be quite large.

5) Administrative Work Load Reduction: Administrative work is a major cost at many installations. On a machine (either physical or virtual) there is exactly one Solaris operating system image and exactly one Solaris Cluster image. This means that the administrator installs the Solaris operating system and the Solaris Cluster software exactly once regardless as to how many zone clusters are deployed. Similarly patches and updates are applied only once. By contrast, the administrator must install one Solaris operating system image and one Solaris Cluster image per virtual machine. Similarly patches and updates must be applied once per virtual machine. Thus the administrative work load for a set of Zone Clusters is much less than for a set of clusters running on virtual machines.

6) Zone Clusters and Virtual Machines: Since it is possible to configure a virtual cluster on a set of virtual machines, the question arises as to why one would want to use Zone Clusters with virtual machines. Here we will identify two use cases. Note that this is not an exhaustive list.

Each virtual machine can run a different kind of operating system. Consider the case where an administrator wants to run both Linux and Solaris applications. The administrator would create two virtual machines on each physical machine, where Linux runs on one virtual machine and Solaris runs on the other virtual machine. In our example the administrator wants to isolate the Solaris applications, because the applications support different organizations. The administrative work load is much less for zones compared to virtual machines. This would motivate the use of Zone Clusters on one set of virtual machines instead of multiple sets of virtual machines.

There are many physical machines that do not support virtual machines based upon hypervisors. On such machines the administrator could use an operating system virtualization solution, such as Zone Clusters. Over time new hardware becomes increasingly powerful. Many commercial systems remain in production for many years. Many people try to avoid changing things. An organization in a few years may choose to consolidate multiple clusters on to one set of hardware using virtual machines. The old clusters could be running different operating system releases and the virtual machines would accomodate that. The existing Zone Clusters on the old physical machines would port directly to the new virtual machine based configuration.

III. Zone Cluster Design

This section provides an overview of the design of a Zone Cluster.

A. Solaris Container

The Solaris Container [1], which is also called a **Zone**, uses an operating system virtualization approach that creates an isolated environment for applications under a single operating system image. Zones were introduced with the Solaris 10 OS.

Each machine hosting Solaris 10 always has exactly one zone, called the global zone. The administrator can create, modify, or destroy non-global zones from the global zone. In the rest of this paper a zone refers to a non-global zone unless global zone is specifically identified.

Zones provide the following primary features:

- Security Isolation - an application or user within a zone cannot see or affect things in other zones.
- Application Fault Isolation - application actions or failures in one zone do not affect other zones. Zone actions, such as zone boot or zone halt, do not affect other zones.
- Resource Management - The zone is a unit of granularity for Solaris Resource Management. The administrator in the global zone can configure specific resources or shares of resources for the use of a specified zone.

Operating system virtualization solutions are available for other operating systems, though feature sets vary. FreeBSD UNIX has Jails [4]. Linux has Virtual Private Server Solution [5], OpenVZ [6], Virtuozzo Containers [7], and VServer [8]. AIX has Workload Partitions [9].

B. Virtual Node

Each virtual node of a Zone Cluster is a zone, and is located on a different machine for high availability. The Zone Cluster nodes can span all of the machines or any subset. The number of Zone Clusters is limited primarily by the resources needed to support the applications in each zone cluster, such as CPUs, memory, storage, etc.

The Solaris OS supports the ability to modify zone behavior through the *BrandZ* framework. The Zone Cluster design introduces a new brand zone, called the **cluster** brand zone. The **cluster** brand zone is based upon the original **native** brand zone. The BrandZ framework provides a number of hooks where behavior can be changed. The Zone Cluster design uses these hooks. For example, the BrandZ hook at boot time has been modified to perform the traditional **native** boot operations and also notify Solaris Cluster software that the zone has booted.

C. Membership

Each Zone Cluster has its own separate membership. The format of the Zone Cluster membership has the same format as the membership information for the original form of a cluster.

The Zone Cluster exists in addition to the original kind of cluster. The original kind of cluster consists of all of the global zones, and hence we call that the Global Cluster. The Zone Cluster relies upon the Global Cluster for a variety of services. Thus the Zone Cluster node cannot come up unless the Global Cluster node on the same machine has already booted.

In order to prevent multiple clusters from being active the Global Cluster requires that greater than half the quorum votes belong to the current partition. If there are only two nodes, the admin must configure a quorum device so that one and only one cluster partition can remain operational after a network partition. The Zone Cluster relies upon the Global Cluster for quorum, and thus the Zone Cluster never needs a quorum device. This is one factor that makes the Zone Cluster easier to manage than the Global Cluster.

D. Security

The Zone Cluster node is a security container. The operating system checks all accesses to all resources, such as networks and file systems. The vehicle for requests is either a system call or a Solaris door call. In addition the operating system attaches to all requests information identifying the request originator. Applications in the zone cannot tamper with this information. The Solaris Cluster software uses this information to validate access rights to cluster resources. The security model treats both kernel and the global zone as secure locations. The overall result ensures correct security. Figure 2 portrays this security model.

E. File Systems

The Solaris Zone feature provides the ability to control which file systems can be accessed from any particular zone. The admin can grant a zone access to a file system without granting direct access to the underlying storage device. Should

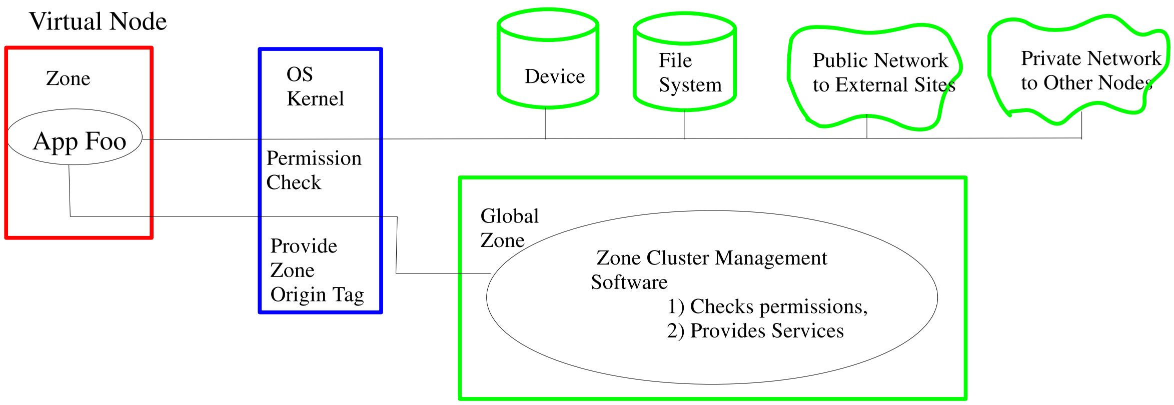

Fig. 2. Zone Cluster Security

an application issue an incorrect ioctl to a device, that can result in failure for all zones on the machine. When file system access is needed, it is safer to configure just the file system into the zone. No performance overhead occurs when only the file system is configured into the zone.

Zone Clusters support multiple kinds of file systems that need different support. The Solaris zone software mounts file systems when booting the zone. This is not always compatible with cluster needs.

A Highly Available File System mounts on one Zone Cluster node at a time. Solaris Cluster moves this file system between Zone Cluster nodes based upon administrative command or automated recovery operations. This can happen at times other than when the Zone Cluster node boots.

A Cluster File System provides read and write access to all Zone Cluster nodes concurrently. The Zone Cluster software manages the mount/unmount of cluster file systems, and also provides automated recovery from error cases, such as machine failure.

F. Storage Devices

The administrator can configure storage devices into a Zone Cluster.

G. Networks

Solaris provides two models for supporting network communications from within a zone. The Zone Cluster design currently uses the *shared* model of network communications. This model shares the NIC and network software stack between the global zone and the non-global zone. The administrator grants the zone access to a specific combination of NIC and IP Address. The Solaris OS ensures that the zone can only use authorized NIC - IP-Address combinations.

Solaris uses **ifconfig** to manage the network interfaces. Unrestricted access would enable an application in one zone to impact other zones. So Solaris does not grant the ability to execute **ifconfig** commands that change state. An important cluster application requires the ability to manage the network interfaces. The Zone Cluster feature set adds the ability of applications in a Zone Cluster to do a limited number of **ifconfig** operations, such as plumb and unplumb, for authorized NIC - IP-Address combinations.

Solaris Cluster handles support of communications between cluster nodes separately from communications with the external world.

1) Public Network Communications: Solaris Cluster supports an IP Address resource that follows an application resource around the cluster. The Solaris Cluster software plumbs and unplumbs the IP address in order to ensure that the IP Address is available to the application regardless of its current node location.

2) Private Network Communications: Solaris Cluster provides a pseudo device that combines the private networks and stripes the communications across these same private networks. The Zone Cluster software automatically configures the system to support the private interconnect inside a Zone Cluster using information from the global zone about the private interconnect configuration. This includes automatically assigning IP addresses from a pool of available IP Addresses.

H. Administration

There are two forms of administration for Zone Clusters.

1) Zone Cluster Administration: The Zone Cluster can only be configured from a global zone in the Global Cluster for security reasons. A non-global zone cannot see or affect another non-global zone, and a non-global zone cannot grant privileges or resources to itself.

The Zone Cluster design intends to ease the burdens on the administrator. The entire Zone Cluster can be administered from any machine in a single command. When configuring the Zone Cluster, the system uses knowledge of the Global Cluster to reduce the amount of information that the administrator must provide. For example, the Global Cluster and the Zone Cluster are likely to use the same time zone. The administrator can always override default values.

The Zone Cluster contains just applications and those specific resources that are used by these same applications. Thus a number of things that can be administered in the Global Cluster are not administered in the Zone Cluster. For example, the administrator never tunes heartbeats in the Zone Cluster.

2) Application Administration: Each Zone Cluster constitutes a separate domain for application administration. An administrator inside a Zone Cluster can do application level administration independently. The information about applications and application resources is kept in a separate place for each Zone Cluster. This provides name space isolation.

There are scenarios where an application in one Zone Cluster has a dependency upon an application in another Zone Cluster. The administrator in the Global Cluster can configure and remove inter-cluster dependencies and location relationships. The administrator in the Global Cluster can also perform application administration for any Zone Cluster.

The Zone Cluster feature set includes both command line interfaces and browser-based user interfaces. The application administratration commands and GUI follow the principle that the administrator can manage the applications and their resources on any node from any node.

Solaris Cluster has wizards to assist the administrator in the configuration of our most popular applications in the Global Cluster. The wizard can greatly simplify work for the administrator when dealing with complicated appplications, such as for a parallel database. The initial release enhanced the configuration wizard to support a parallel database.

IV. Performance Comparisons

Now that we have multiple cluster virtualization solutions, one of the first questions is what impact do these virtualization solutions have on performance. We decided to examine performance in three basic areas. We begin with an application level benchmark to guage the overall impact on performance. File system and network performance are critical to application performance. So we continued our examination with benchmarks in both of these areas. We realize that there are many possible ways to examine performance. Our primary goal is to provide an initial indication of performance by choosing representative tests.

A. Platforms

The cluster hardware consists of 2 SunFire T2000 machines. Each machine contains 24 CPUs and 8GB memory. The NICs are all e1000g devices. A pair of e1000g devices on each machine are configured into an IP MultiPathing (IPMP) group for public network communications. The cluster has two private networks that form the cluster private interconnect for inter-node communications. A single e1000g device connects the machine to each private network. Thus 2 NICs connect to separate private networks to support inter-node communications. A Sun StorEdge 3511 device provides the file system storage and is connected to all nodes via SAN.

All machines are installed with Solaris 10 update 6 and Solaris Cluster 3.2 1/09.

The first configuration consists of a Global Cluster on physical machines with no Zone Clusters. The Global Cluster has access to all CPUs and memory. In the figures we use the abbreviation **GZ** to represent this configuration.

The second configuration consists of a Zone Cluster on physical machines that spans both machines. Since a Zone Cluster cannot exist without a Global Cluster, there also is a Global Cluster in this configuration. The Global Cluster did not run any applications during the test runs. The Zone Cluster was configured with 20 CPUs and had a memory cap of 6GB. In the figures we use the abbreviation **ZC** to represent this configuration.

The third configuration consists of a Global Cluster on LDom Guest Domain virtual machines with no Zone Clusters. Each LDom Guest Domain has 20 CPUs and 6GB of memory. The LDom Guest Domains do not have direct access to physical devices. The virtual device driver in the LDom Guest Domain communicates with a real device driver in the LDom I/O Domain, which in this case is also the LDom Control Domain. The real device driver then communicates with the network or storage devices. There is no Zone Cluster in this configuration. In the figures we use the abbreviation **GZ-VM** to represent this configuration.

The fourth configuration adds a Zone Cluster to the set of LDom Guest Domain virtual machines described in the third configuration. We do not limit the CPUs or memory for the Zone Cluster, but the Zone Cluster can not use any CPU or memory not already configured for that LDom Guest Domain. In the figures we use the abbreviation **ZC-VM** to represent this configuration.

B. Application Level Benchmark

We chose the Apache application for our application level benchmark runs. Apache is relatively simple to configure and a benchmark was already available. We configured the Apache2 web server on one cluster node. On that same node we created a simple html file. On the other node of the cluster we ran the Apache Benchmark (AB) [10]. The test makes 10000 requests with the number of concurrent requests set to 20. Each request results in the transfer of the html file.

Figure 3 shows the Apache AB application benchmark results in terms of operations per second. Each operation is one http file request. Table I shows the performance of the different cluster configurations relative to that of the Global Cluster on physical machines. The results show that the Zone Cluster solution using operating system virtualization on physical machines adds no significant performance overhead. The virtual machine solutions add measurable performance overhead.

TABLE I
Apache AB Relative Performance

Performance Relative to Global Cluster on Real Machine		
ZC	**GZ-VM**	**ZC-VM**
100%	94%	87%

C. File System Level Benchmark

We chose the file system benchmark Filebench [11]. The benchmark was run on a UFS file system of 20GB size created

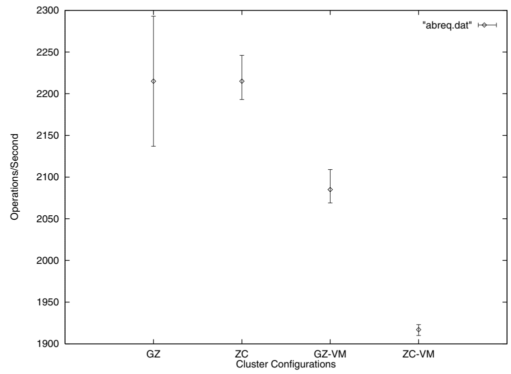

Fig. 3. Apache AB benchmark results for different cluster configurations

on Sun StorEdge 3511 SAN box connected to the cluster nodes. Filebench is capable of executing a wide variety of file system work loads. We ran the *varmail* profile of filebench, which mimics a mail store. This is similar to the Postmark [12] test suite. The test creates 50,000 small files on the file system, all in the same directory. The test then performs file operations on those files from 20 threads for a period of 30 seconds per run. The test reports the number of file operations per second.

Figure 4 shows the Filebench file system benchmark results in terms of file operations per second. Table II shows the performance of the different cluster configurations relative to that of the Global Cluster on physical machines. The results show that all of the cluster configurations perform similarly on this benchmark.

TABLE II
FILEBENCH RELATIVE PERFORMANCE

Relative to Global Cluster on Real Machine		
ZC	**GZ-VM**	**ZC-VM**
100.1%	99.9%	100.0%

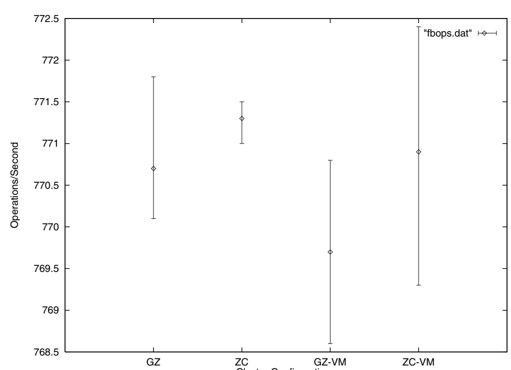

Fig. 4. Filebench benchmark results for different cluster configurations

D. Network Level Benchmark

We chose the Uperf network benchmark [13]. Uperf is capable of exercising a wide range of network work loads. We used the iperf profile for TCP communications, which mimics the iperf benchmarking tool [14]. The uperf 'slave' starts on one node of the cluster. The 'master' starts on another node and spawns 20 threads that write TCP data to the slave. The slave also spawns 20 threads to receive data. The total amount of user data written to the slave over a period of 60 seconds is measured, to calculate the TCP throughput. All communications go over the cluster private interconnect. Solaris Cluster has a pseudo network driver that stripes the communications across both private networks.

Figure 5 shows the Uperf network benchmark results in terms of operations per second. Table III shows the performance of the different cluster configurations relative to that of the Global Cluster on physical machines. At first glance, these results would tend to indicate that virtual machine solutions improved performance. Since we know that the network communications were going through more layers of software, this seemed counter-intuitive. So we investigated further.

TABLE III
UPERF NETWORK RELATIVE PERFORMANCE

Performance Relative to Global Cluster on Real Machine		
ZC	**GZ-VM**	**ZC-VM**
99.3%	104.5%	108%

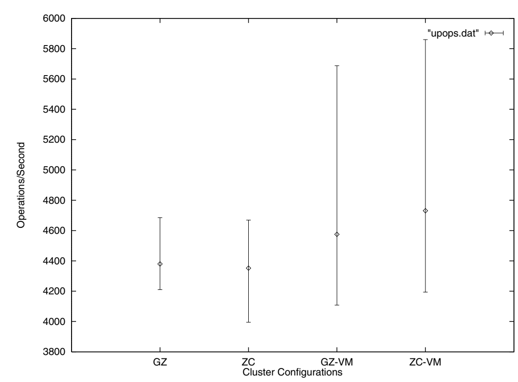

Fig. 5. Uperf network benchmark results for different cluster configurations

The Uperf benchmark provides separate information on the performance of each NIC. Since this is a high availability cluster, we use two NICs for communications between nodes. We observed that the performance of the second NIC varied wildly, whereas the performance of the first NIC was much more consistent. So we chose to compare the performance of the first NIC on different cluster configurations. Figure 6 shows the Uperf network benchmark results in terms of operations per second for the first NIC. Table IV shows the performance of the different cluster configurations relative to that of the Global Cluster on physical machines. This shows that that the performance differences are much smaller in this case.

Table V shows the range in performance for both NICs. The Zone Cluster on virtual machines only had one result outside the range 1.80-1.82 Mb/s for NIC1. Similarly, the Zone

Cluster NIC1 on physical machines had only one result outside the range of 1.77-1.80 Mb/s. Thus, the performance of the first NIC was very consistent across all configurations. These results indicate that the performance of the second NIC is an area where performance improvements may be possible. Virtualization technologies are still maturing. So it is not surprising that we have found an area for improvement.

TABLE IV
UPERF NETWORK RELATIVE PERFORMANCE ON FIRST NIC

Performance Relative to Global Cluster on Real Machine		
ZC	**GZ-VM**	**ZC-VM**
99.4%	100.8%	103.2%

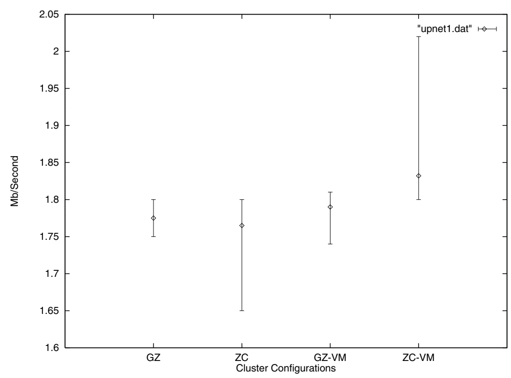

Fig. 6. Uperf first NIC results for different cluster configurations

TABLE V
UPERF NETWORK PERFORMANCE RANGE FOR NICS

Uperf NIC Performance Ranges in Mb/s				
NIC	**GZ**	**ZC**	**GZ-VM**	**ZC-VM**
NIC1	1.75-1.80	1.65-1.80	1.74-1.81	1.80-2.02
NIC2	1.48-1.82	1.42-1.81	1.20-2.46	1.21-2.20

E. Overall Performance Evaluation

The Solaris Zone adds a permission check to actions that manipulate resources. For example, when an application opens a file, the Solaris OS checks whether the zone hosting that application has authorization to access that file. Once the file is open, there is no zone overhead for read and write operations. Thus, we expected to find insignificant overhead for Zone Clusters. On physical machines the results confirm that no significant overhead is added by placing applications in zones. The overhead for the application benchmark in a Zone Cluster on virtual machines, showed a modest overhead. On other benchmarks a Zone Cluster on virtual machines showed no significant overhead.

The Global Cluster on virtual machines showed modest overhead on the application benchmark. On the file system and network benchmarks the overall performance was in line with that of physical machines. The Global Cluster on virtual machines showed significantly greater performance variation on the file system and network benchmarks. The LDom software is much newer than zone software. So the LDom software may not have matured as much in the area of performance. The LDom solution adds overhead because of the additional work being done by the hypervisor and the interposition of a pseudo device driver on communications with device. So we expected some drop in performance. The greater variation was surprising. It would be a good idea to revisit LDom performance as the LDom software matures.

An interesting next step would be to look at the relative performance as more zone clusters with work loads are added. The hardware used for the performance runs has a lot of CPUs in each machine, which could be masking different overheads in the different technologies. There seems little reason to use virtualization technologies in the case where only one cluster is used. So one can expect multiple clusters on a single set of hardware when using virtualization technologies.

V. CONCLUSION

The Zone Cluster introduces the first virtual high availability cluster based upon operating system virtualization in a commercial product, at least as far as could be determined. Multiple commercial high availability cluster products support the ability to start and stop applications in operating system virtualization containers, but that is not equivalent to a virtual cluster.

The Zone Cluster provides the following important features:

- Security Isolation
- Application Fault Isolation
- Resource Management
- Cost Containment

Performance benchmarks show that Zone Clusters do not introduce significant overheads when compared to the Global Cluster, especially on physical machines.

Performance on virtual machines is more variable than on physical machines. However, overall performance on virtual machines is not seriously degraded.

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